09/508683
416 Rec'd PCT/PTO 28 MAR 2000

SUBSTITUTE SPECIFICATION

9847-0044-6X PCT
ENKEL 8303

TITLE OF THE INVENTION

POWER TRANSFORMER/REACTOR AND A METHOD OF ADAPTING A HIGH VOLTAGE CABLE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates in a first aspect to a power transformer/reactor. A second aspect of the present invention relates to a method of adapting a high voltage cable for windings of a power transformer/reactor

Discussion of the Background

For all transmission and distribution of electric energy, transformers are used and their task is to allow exchange of electric energy between two or more electric systems having generally different voltage levels. Transformers are available in all power ranges from the VA up to the 1000 MVA range. With respect to the voltage range, there is a spectrum up to the highest transmission voltages which are being used today. Electromagnetic induction is used for the transmission of energy between electric systems.

For the transmission of electric energy, reactors are also included as an essential component, for example for phase compensation and filtering.

The transformer/reactor relating to the present invention belongs to the so-called power transformers/reactors with a rated output ranging from a few hundred kVA up to more than 1000 MVA with a rated voltage ranging from 34 kV and up to very high transmission voltages.

From a purely general point of view, the primary task of a power transformer is to allow exchange of electric energy between two or more electrical systems usually having different voltages with the same frequency.

A conventional power transformer/reactor comprises a transformer core referred to below as core, made of laminated preferably oriented sheets, usually of silicon steel. The

core is made of a number of core legs connected by yokes. Around the core legs there are a number of windings which are normally referred to as primary, secondary and regulation winding. As far as power transformers are concerned these windings are practically always concentrically arranged and distributed along the length of the core legs.

Other types of core constructions occasionally occur such as those of the so-called shell-type transformer or the toroidal-type transformer. Examples relating to core constructions are described in for example DE 40414. The core may be made of conventional magnetizable material such as said oriented steel sheet, and of other magnetizable material such as ferrites, amorphous material, wire strands or metal tape. With respect to reactors, the magnetizable core is as known not necessary.

The above-mentioned windings constitute one or several coils connected in series, which coils are constructed of a number of turns connected in series. The turns of a single coil normally make up a geometrically continuous unit which is physically separated from the remaining coils.

The insulation system, partly on the inside of a coil/winding and partly between coils/windings and other metal parts is normally in the form of a solid cellulose or varnish based insulation closest to the separate conducting element and the insulation on the outside is in the form of a solid cellulose insulation, a fluid insulation and possibly an insulation in the form of a gas. Windings having insulation and possible bulky parts represent in this way large volumes that will be subjected to high electric field strengths occurring in and around the active electro-magnetic parts belonging to transformers. A detailed knowledge of the properties of insulation material is required in order to predetermine the dielectric field strengths which arise and in order to attain a dimensioning such that there is a minimal risk of electric breakdown. Furthermore it is important to achieve a surrounding environment which does not change or lead to the deterioration of the insulation properties.

Today's predominant outer insulation system for conventional high voltage power transformers/reactors consists of cellulose material for the solid insulation and transformer oil for the fluid insulation. Transformer oil is based on so-called mineral oil.

Additionally, a conventional insulation is relatively complicated to construct and special measures need to be taken during manufacture in order to utilize the good insulation properties of the insulation system. The system should have a low moisture content, the solid phase in the insulation system needs to be well impregnated with the surrounding liquid, the

risk for remaining gas pockets in the solid phase must be minimal. During manufacture a special drying process is carried out on the complete core with windings before it is lowered into the tank. After lowering the core and sealing the tank, the latter is emptied of all air by means of a special vacuum treatment before being filled with oil. This process is relatively time consuming seen from the entire manufacturing process in addition to requiring the extensive utilization of resources in the workshop.

The tank surrounding the transformer must be constructed in such a way that is able to withstand full vacuum since the process requires that all the gas be pumped out to almost absolute vacuum which involves extra material consumption and manufacturing time.

Furthermore, the installation on site requires renewed vacuum treatment, a process to be repeated each time the transformer is opened for attention or for inspection.

SUMMARY OF THE INVENTION

The power transformer/reactor, according to the present invention, includes at least one winding arranged in most cases around a magnetizable core which is of varying geometry. The term "windings" will preferably be referred to below in order to simplify the following specification. The windings are formed of a high voltage cable having solid insulation. The cables are made of at least one centrally located electric conductor around which there is arranged a first semiconducting layer, around the first semiconducting layer there is arranged a solid first insulating layer and around the insulating layer there is arranged a second outer semiconducting layer.

An additional advantage is that the layers are arranged to adhere to one another even when the cable is bent. Hereby, good contact is achieved between the layers during the cable's entire life.

The second semiconducting layer is directly earthed at n points of each winding, where n is an integral number and $n \geq 2$, and whereby two of the directly earthed points are arranged at or in the vicinity of both ends of each winding. The electric contact is interrupted 2(n-1) times in the second semiconducting layer. The second semiconducting layer of different phases at each interruption is earthed in a cross-connected manner.

A method for adapting a high voltage cable for windings of a power transformer/reactor, according to the present invention, comprises the following steps:

- directly earthing the second semiconducting layer at n points of each winding

where n is an integral number and $n \geq 2$, and whereby two of the points are arranged at or in the vicinity of both ends of each winding;

- achieving two interruptions in the electric contact in the second semiconducting layer between each pair of directly earthed points; and
- earthing in a cross-connected manner the second semiconducting layer at different phases of each interruption.

The use of such a cable implies that those areas of the transformer/reactor which are subjected to high electric field stress are limited to the solid insulation of the cable. Remaining parts of the transformer/reactor, with respect to high voltage application, are only subjected to very moderate electric field strengths. Furthermore, the use of such a cable eliminates several problematic areas described in the background of the invention. Consequently a tank is not needed for the insulating and cooling medium. Besides, the insulation also becomes substantially simple. Construction time is considerably shorter compared to that of a conventional power transformer/reactor. The windings may be manufactured separately and the power transformer/reactor may be assembled on site.

However, the use of such a cable presents new problems which must be solved. The outer semiconducting layer must be directly earthed at or in the vicinity of both ends of the cable so that the electric stress, which arises both at normal operating voltage and during transience, will primarily only load the solid insulation of the cable. The semiconducting layer in addition to these direct earthings form a closed circuit in which a current is induced during operation. The resistivity of the layer must be great enough so that the resistive losses arising in the layer are negligible.

Besides this magnetically induced current, a capacitive current will flow into the layer through the direct earthing in both ends of the cable. If the resistivity of the layer is too great, the capacitive current will become so limited that the potential in parts of the layer, during a period of alternating stress, may differ to such an extent from the earth potential that areas of the power transformer/reactor other than the solid insulation of the windings will be subjected to electric stress. By breaking the electric contact n amount of times, where n is an integral number and $n \geq 1$, in the second semiconducting layer between both ends of the cable and by earthing the second semiconducting layer at different phases in cross-connected manner at each said interruption, the current in the second semiconducting layer is eliminated

and the power losses are minimized.

All interruptions in the second, outer semiconducting layer of a high voltage cable will result in an increase of the electric field strength at the edge of the second semiconducting layer at the interruption. This increase of the electric field strength clearly increases the risk for electric breakdown. By arranging a means comprising a second insulation layer and a third semiconducting layer at each interruption in the second semiconducting layer, the risk for electric breakdown is minimized.

In extreme cases the windings may be subjected to such rapid transient overvoltage that parts of the outer semiconducting layer assume such a potential that areas of the power transformer other than the insulation of the cable are subjected to undesirable electric stress. In order to prevent such a situation from arising a number of non-linear elements, e.g. spark gaps, gas diodes, zener-diodes or varistors are connected between the layer and earth for each phase. By connecting a capacitor between the outer semiconducting layer and earth, undesirable electric stress may also be prevented from arising. A capacitor reduces the voltage stress even at 50Hz. This principle of earthing will be referred to below as "indirect earthing".

The indirectly earthed points are connected to earth either via the following;

- a non-linear element e.g. a spark gap or a gas diode,
- a non-linear element parallel to a capacitor,
- a capacitor

or a combination of all three alternatives.

The invention will now be described in more detail in the description hereinafter of the preferred embodiments of the invention with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a cross-sectional view of a high voltage cable;

Figure 2A shows a partly sectional view of a high voltage cable having interruptions in the second semiconducting layer in order to illustrate the amplification of the electric field at the edges of the interruption; and

Figure 2B shows a perspective view of a part of the cable shown in Figure 2A;

Figure 3 shows a cross-sectional view along the longitudinal axis of the cable on a

high voltage cable having a means to reduce the amplification of the electric held strength at the interruption;

Figure 4 shows a schematic principle of earthing a three phase power transformer according to the present invention;

Figure 5 is a diagram showing the potential of the second semiconducting layer in relation to the length of the cable;

Figure 6a and 6b, respectively, show different elements in order to achieve indirect earthing; and

Figure 7 shows a flow chart of the method of adapting a high voltage cable according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 shows a cross-sectional view of a high voltage cable 10 traditionally used for the transmission of electric energy. The shown high voltage cable 10 may for example be a standard XLPE cable 145 kV but without a mantle and a screen. The cable 10 used in the present invention is flexible and of a kind which is described in more detail in WO 97/45919 and WO 97/45847. Additional descriptions of the cable concerned can be found in WO 97/45918, WO 97/45930 and WO 97/45931. The high voltage cable 10 has an electric conductor which may include one or several strands 12 having a circular cross section of for example copper (Cu). These strands 12 are arranged centrally in the high voltage cable 10. Around the strands 12 there is arranged a first semiconducting layer 14. Around the first semiconducting layer 14 there is arranged a first insulating layer 16, of for example XLPE insulation. Around the first insulating layer 16 there is arranged a second semiconducting layer 18.

In fig. 1 showing the detail of the invention relating to the cable 10, the three layers 14, 16, 18 are arranged to adhere to each other even when the cable 10 is bent. The cable 10 shown is flexible, and this property is maintained during the entire life of the cable.

Accordingly, the windings, in the arrangement according to the invention, are preferably of a type corresponding to cables having solid, extruded insulation, of a type now used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable includes an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and

an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the arrangement according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of an XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable with a diameter of 30 mm, and a radius of curvature of approximately 65 cm for a cable with a diameter of 80 mm. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE-cable, for instance, the insulating layer is made of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may be made of, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene ("TPX"), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber (EVA/NBR), butyl graft polyethylene, ethylene-butyl-acrylate copolymers (EBA) and ethylene-ethyl-acrylate copolymers (EEA) may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently high to enclose the electrical field within the cable, but sufficiently low not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

Figure 2A shows a view, partially cross-sectional, of a high voltage cable having interruptions in the second semiconducting layer in order to illustrate the amplification of the electric field strength at the edges of the interruption. The section shown in 2A extends along the longitudinal axis of the high voltage cable. Figure 2B shows a perspective view of a part of the cable shown in Figure 2A. Like parts in Figures 2A and B have been designated

by the equivalent reference numbers. The strands 12 are only shown schematically in Figure 2A. As shown in Figures 2A and B the second semiconducting layer 18 has been removed in the shape of a ring around the periphery of the high voltage cable 10 so that a groove 20 is formed. In this way the first insulation layer 16 is exposed in the groove 20. By achieving this interruption in the electric contact located between two earthing points, in the second semiconducting layer 18, no current will flow and thus no loss of heat will occur due to induced voltage. However all interruptions in the second semiconducting layer 18 give rise to an amplification of the electric field strength at the sides of the interruption. As shown in Figure 2A, the electric field lines are illustrated (indicated by the reference number 22). At the edges of the groove 20 there is a concentration of field lines 22 which means~that the electric field strength shows a sharp increase. This unfortunately results in an increased risk for electric discharge, the aim being to strive towards avoiding this occurrence.

Figure 3 shows a cross-sectional view along the longitudinal axis of the cable of a high voltage cable having a mechanism to reduce the amplification of the electric field strength at the interruption. The high voltage cable 10 includes, in the same way as the high voltage cable according to Figure 1, the following: strands 12; a first semiconducting layer 14; a first insulating layer 16 and a second semiconducting layer 18. As shown in Figure 3 the second semiconducting layer 18 has been removed in the shape of a ring around the periphery so that a groove 20 is formed, exposing the first insulating layer 16. As shown in Figure 3 the groove 20 has downward sloping edges i.e. the groove 20 has a larger breadth at the upper edge of the second semiconducting layer 18 than that of the first insulating layer 16. The groove 20 may for example have straight edges even though downward sloping edges are advantageous. The distance between the edges of the second semiconducting layer 18 of the first insulating layer is indicated by b in Figure 3. The width b of the groove 20 is preferably 10 mm. Besides, the high voltage cable 10 includes a second insulating layer 24 which is applied among other things onto the groove 20 so that the groove 20 is filled in this way. The reason for having sloping edges at the groove 20 is in order to avoid obtaining a hollow space at the edges when the second insulating layer 24 is formed by filling among other things the groove 20 with a suitable insulating material, for example insulating "self amalgamating" EPR-tape such as the insulating tape IV-tape®, IA 2332 from ABB Kabeldon. The second insulating layer 24 covers even the sloping edges of the second semiconducting layer 18 and a part of the second semiconducting layer 18 to the side of the

sloping edges. Besides, the high voltage cable 10 has a third semiconducting layer 26, for example in the form of tape such as the semiconducting tape, HL-tape®, IA 2352 from ABB Kabeldon, which is applied over the second insulating layer 24 in such a way that the one end of the third semiconducting layer 26 covers one edge of the second insulating layer 24 and has electric contact to the second semiconducting layer 18. The other end of the third semiconducting layer 26 does not cover the other side of the second insulating layer 24 but stops at a distance c from the other edge of the second insulating layer 24. The second insulating layer 24 should at least be 1 mm thick at the edge where the third semiconducting layer 26 does not cover the second semiconducting layer 24. However, the third semiconducting layer 26 must be stretched at its other end over (overlapping) the second semiconducting layer 18 located under the second insulating layer 24. The distance between the edge of the third semiconducting layer 26 and the edge of the second semiconducting layer 18 in the longitudinal direction of the cable 10 is d as shown in Figure 3. The third semiconducting layer 26 should be at least 1 mm thick.

Figure 4 shows schematically the earthing principle for a three phase power transformer/reactor in accordance with the present invention. Windings are shown as drawn out cables in order to clarify the Figure. Besides, a possible core of the three phase power transformer has been omitted. Three phase power transformers comprise three windings 1, 2, 3 representing the different phases 1, 2, 3. Each winding 1, 2, 3 is constructed with the high voltage cable 10 shown in Figure 1. The cables for the different phases are designated as 10_1, 10_2, 10_3. The second semiconducting layer of each high voltage cable 10_1,10_2,10_3 is directly earthed at the points 32, 34 which are located at or in the vicinity of both ends of each winding 1, 2, 3. Generally, the second semiconducting layer 18 is directly earthed at n points of each winding 1, 2, 3, where n is an integral number and $n \geq 2$, and whereby two of said directly earthed points are arranged at or in the vicinity of both ends of each winding 1, 2, 3. This direct earthing is performed by way of a galvanic connection to earth. Besides, the electric contact in the second semiconducting layer is interrupted two times 20_{11}, 20_{21}, 20_{31}, 20_{12}, 20_{22}, 20_{32} per winding 1, 2, 3. The electric contact in the second semiconducting layer 18 is generally interrupted 2(n-1) times per winding 1, 2, 3. Even if not shown in Figure 4 there may be found arranged at each such interruption 20 a mechanism 24, 26 having a second insulating layer 24 and a third semiconducting layer 26 in order to reduce the amplification of the electric held strength at said interruption 20. This mechanism 24, 26 is

shown in Figure 3. The second semiconducting layer 18 of the three phases 1, 2, 3 at each interruption 20_{11}, 20_{21}, 20_{31}, 20_{12}, 20_{22}, 20_{32} is earthed in a cross-connected manner. Besides, the second semiconducting layers 18 of the three phases 1, 2, 3 are indirectly earthed at two points 36, 38. Generally speaking, the number of indirectly earthed points may vary. As in the shown case the indirect earthing is performed by way of spark gaps 40. The indirect earthing may be performed in a number of different ways as for example in the aforementioned under the heading "Summary of the invention" and as shown in the Figures 6a, 6b. Cross-connected earthing 42, 44 is achieved through the second semiconducting layers 18 of the different phases 1, 2, 3 being connected at each said interruption 20_{11}, 20_{21}, 20_{31}, 20_{12}, 20_{22}, 20_{32} and being indirectly earthed via a spark gap 40. A more detailed description of cross-connected earthing will be discussed hereinafter.

The power transformer 30 in Figure 4 is provided with two interruptions 20_{11}, 20_{21}, 20_{31}, 20_{12}, 20_{22}, 20_{32} per phase 1, 2, 3 and thus three continuous sections 18_{11},18_{12}, 18_{13}; 18_{21}, 18_{22}, 18_{23}; 18_{31}, 18_{32}, 18_{33} of the second semiconducting layer 18 per phase 1, 2, 3. At the first interruption 20_{11}, the first section 18_{11} of the second semiconducting layer 18 of the first phase 1 is connected to the second section 18_{22} of the second phase 2. Besides, the first section 18_{11} of the first phase 1 is connected to the first section 18_{21}, 18_{31} of the remaining phases 2, 3 and connected to indirect earthing by way of a spark gap 40. The first section 18_{21} of the second phase 2 is connected to the second section 18_{32} of the third phase 3. Besides, the second section 18_{12} of the first phase 1 is connected to indirect earthing by means of the spark gap 40. Correspondingly, cross-connected earthing is applied to the second interruption 20_{12} and is not repeated herein. Another way of describing this cross-connected earthing is to follow the connections from a direct earthing point to the next earthing point. To start with the direct earthing point 32, is followed by the first section 18_{11} of the first phase 1, which section 18_{11} is connected to the second section 18_{22} of the second phase 2, which section 18_{22} is connected to the third section 18_{33} of the third phase 3, which is connected to direct earth via the point 34. Correspondingly, sections 18_{21}-18_{32}-18_{13} are connected between both of the direct earthing points 32, 34. Correspondingly, sections 18_{31}-18_{12}-18_{23} are connected between both of the direct earthing points 32, 34. However, a general description of cross-connected earthing in a power transformer/reactor will be described hereinafter where there are n number of direct earthing points per phase.

Generally speaking from the point of view of one case, the second semiconducting

layer 18 is directly earthed at n number of points of each winding 1, 2, 3 where n is an integral number and $n \geq 2$, and whereby two of said n directly earthed points are arranged at or in the vicinity of both ends of each winding 1, 2, 3. This means that the electric contact is interrupted 20 2(n-1) amount of times in the second semiconducting layer 18 between both ends, seeing that there are two interruptions 20 between each pair having directly earthed points. This means that there exists 3(n-1) sections of the second semiconducting layer 18 per phase 1, 2, 3, whereby one section begins at a directly earthed point or interruption 20 and ends at an interruption 20 or a directly earthed point.

At interruption 20 number q, where $1 \leq q \leq 2(n-1)$, of the different phases there is section r, where $1 \leq r \leq 3(n-1)$, of the second semiconducting layer 18 of one phase which is connected to section (r+1) of the second semiconducting layer 18 of the consecutive phase. Besides, section r of the first phase is connected to section r of the remaining phases. Section r of the last phase and section (r+1) of the first phase are connected to the indirect earthing by means of a spark gap 40. The aforementioned does not apply to r evenly divisible by 3, except for the last section, i. e. r=3(n-1) for a given n.

Figure 5 shows a diagram illustrating the potential of the second semiconducting layer 18 extending along the length of the cable. A power transformer having a Y connected winding is referred to in this case. This results then in that the voltage on the second semiconducting layer of the cable winding reduces linearly from the HV-connection to the neutral point under AC-voltage. Let the direct earthing points be designated A and D, and the two points for cross-connected earthing be designated B and C. Designate the distance between the direct earthing points A and D as L, the distance between A and B as I_1, the distance between B and C as I_2 and the distance between C and D as I_3. If the ratio between the distance I, I_2 and I_3 is $I_1 < I_2 < I_3$ and the surface potentials of the second semiconducting layer at the points B and C have the same value, as indicated in Figure 5, the current will be 0 in the second semiconducting layer, which means that the power losses in the second semiconducting layer will be negligible. The distances I_1-I_3 and L are dependent on the dimension of the winding cable in addition to the thickness and the resistivity of the second semiconducting layer.

Figures 6a and 6b respectively, illustrate different elements in order to achieve indirect earthing. In Figure 6a, indirect earthing takes place by means of a circuit 50 comprising one element 52 having a non-linear voltage-current characteristic which is

connected in parallel with a capacitor 54. In the shown case, the element 52 having a non-linear voltage-current characteristic is designed having one spark gap 52. The element 52 may also be designed having a gas-filled gas diode, a zener-diode or a varistor. In Figure 6b, indirect earthing takes place by means of a zener-diode 56.

Figure 7 shows a flow chart illustrating a method for adjusting a high voltage cable 10 (compare to Figure 1) comprising an electric conductor around which there is arranged a first semiconducting layer 14, around the first semiconducting layer 14 there is arranged a first insulating layer 16, and around the first insulating layer 16 there is arranged a second semiconducting layer 18. The method in accordance with the invention comprises a number of steps which will be described hereinafter. The flow chart starts at block 60. The next step, at block 62, is to indirectly earth 32, 34 the second semiconducting layer 18 at n points of each winding 1, 2, 3 where n is an integral number and n≥2, and whereby two of said n points are arranged at or in the vicinity of both ends of each winding 1, 2, 3. Thereafter, at block 64, two interruptions 20 are achieved between each pair of directly earthed points in the electric contact in the second semiconducting layer 18. Thereafter, at block 66, a mechanism 24, 26 is applied at each interruption 20 in the second semiconducting layer 18, which mechanism comprises a second insulating layer 24 and a third semiconducting layer 26 in order to reduce the amplification of the electric field at interruption 20. Thereafter, at block 68, the second semiconducting layers of the different phases 1, 2, 3 are earthed in cross-connected manner at each said interruption 20. Thereafter, at block 70 at least one point 36, 38 of the second semiconducting layer 18 of each phase 1, 2, 3 is indirectly earthed between both ends. The method is concluded at block 72. Reference is made to Figures 2 - 6 regarding further details relating to the method.

It should be indicated that power transformers/reactors may be manufactured with a magnetizable core and also manufactured without a magnetizable core.

The invention is not limited to the embodiments described in the foregoing, several modifications are possible within the scope of the appended claims.